EXHIBIT 1

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

GEODYNAMICS, INC.,	
Plaintiff,	**Civil Action No. 2:17-cv-00371-RSP**
v.	
DYNAENERGETICS US, INC.,	**JURY TRIAL**
Defendant.	

GEODYNAMICS' FEDERAL RULE OF CIVIL PROCEDURE
<u>RULE 26(a)(2)(C) DISCLOSURE OF JOHN HARDESTY</u>

GEODynamics submits the following Federal Rule of Civil Procedure 26(a)(2)(C) disclosure of John Hardesty. GEODynamics reserves the right to supplement this disclosure in order to allow appropriate addition of subject matter, facts, and opinions made known or discovered during further discovery, investigation, or subsequent disclosure.

Mr. Hardesty will testify as to the procedure used during GEODynamics' testing of DPEX, HaloFrac, and CONNEX shaped charges. The testing procedure is detailed in Exhibit 1. Mr. Hardesty will testify about his knowledge of the test set-up and test objectives. Mr. Hardesty will further describe the design of the testing system as well as the implementation of the design. Mr. Hardesty will testify about his opinion that the tests he performed are reliable and simulate the conditions to which a liner is subjected downhole. Mr. Hardesty intends to use photographs of the testing in connection with his testimony. The photographs have been produced at GEOD3 004856 - GEOD3 005118.

Mr. Hardesty will testify about API section II and section IV tests. Exhibit 2 (section II test procedure); Exhibit 3 (section IV test procedure). Mr. Hardesty will testify about his opinions regarding the effectiveness by which Section II and Section IV tests recreate downhole conditions. Mr. Hardesty will testify about the value and deficiencies of Section II and IV tests. Mr. Hardesty will further testify about Section II tests that were conducted with DPEX, HaloFrac, CONNEX, and RAZOR shaped charges. The procedure for the Section II tests performed by Mr. Hardesty is attached as Exhibit 4. Specifically, Mr. Hardesty will explain the differences between the perforation tunnels created by DPEX, HaloFrac, CONNEX, and the RAZOR shaped charges in the Section II test. Mr. Hardesty will testify about his opinion that the tunnel characteristics show that DPEX and HaloFrac charges produced an exothermic reaction. Mr. Hardesty intends to use the photographs at the bates range GEOD3 004589 - GEOD3 004855 and GEOD3 005187 - GEOD3 005193 in conjunction with his testimony on tunnel geometry.

Mr. Hardesty intends to testify regarding certain secondary considerations of non-obviousness. Specifically, Mr. Hardesty will testify regarding industry skepticism of reactive shaped charges, a long-felt but unsolved need for perforating products that can be used in overbalanced well conditions, industry skepticism as to the effectiveness of CONNEX even after its release (such as the Schlumberger and Halliburton early studies), and the commercial success of the CONNEX shaped charge. Mr. Hardesty reserves the right to supplement this disclosure should additional relevant facts or evidence be made available or discovered.

Dated: June 4, 2018

Respectfully submitted,

/s/ Scott W. Hejny

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ATTORNEYS FOR PLAINTIFF

CERTIFICATE OF SERVICE

I hereby certify that on June 4, 2018, a true and correct copy of the above and foregoing document has been served via electronic mail upon counsel of record.

/s/ Scott W. Hejny
Scott Hejny

EXHIBIT 1

I. Reactive Liner Test Objective

1. Develop a test method that simulates a shaped charge liner detonation.
2. Develop a test method that simulates the amount of energy that reactive liner material is exposed to when a reactive shaped charge is detonated.
3. Develop a test method that allows for collection of the products of a reactive liner exothermic reaction.
4. Develop a test that allows the products of a reactive liner exothermic reaction to be examined by elemental analysis.

II. Reactive Liner Test Description

A. Test Hardware

The reactive liner test hardware consists of:

1. Calibration liners
    a. Liner containing 15% Ni, 15% Al, 25% Cu, 6% Pb, and 39% W.
    b. Liner containing 10% Ni, 10% Al, 25% Cu, 6% Pb, and 49% W.
    c. Liner containing 5% Ni, 5% Al, 25% Cu, 6% Pb, and 59% W.
2. DPEX Reactive Shaped Charges
    a. 26g DPEX RDX (part no. 2317007) (mfg date: 10/13/2016)
    b. 26g DPEX HMX (part no. 2317008) (mfg date: 01/04/2017)
    c. 26g DPEX RDX (part no. 2317007) (mfg date: 02/20/2017)
    d. 39g DPEX RDX (part no. 2317128) (mfg date: 03/2014)
3. HaloFrac Reactive Shaped Charges
    a. 22.7g F.O. HMX HaloFrac (part no. 2328553) (mfg date: 02/01/2018)
4. CONNEX Reactive Shaped Charges
    a. 22.7g CONNEX HMX (part no. EC2-33A2342-RC) (mfg date: 30/03/2016)
5. Electric Initiator to dislodge liner.
6. 32g flat input charge
7. Steel Piston and Barrel Fixture
8. Detonation cord
9. Detonation wire
10. # 50 sieve

B. Test Procedure

1. Remove reactive liner from shaped by detonating an electric initiator positioned parallel to and in contact with the shaped charge sample.

2. Clean reactive liner, making sure to remove all HMX or RDX explosive.

3. Remove any portions of reactive liner material that contain epoxy or other adhesive used in fabrication of the shaped charge.

4. Hand-crush reactive liner material.

5. Sieve reactive liner material in # 50 sieve.

6. Pour reactive liner material into cavity in steel barrel and ensure material is equally distributed within collection cavity.

7. Insert steel piston into barrel cavity and ensure that piston is in full contact with the powder liner material such that there is no empty space between barrel, liner material, and piston.

8. Use electrical tape to ensure piston remains in contact with reactive liner material.

9. Rotate barrel such that piston is resting on surface and place 32g input charge on top of steel barrel. Ensure that the input charge is centered on the steel barrel.

10. Insert detonation cord into input charge and use electrical tape to ensure input charge remains centered on the steel barrel.

11. Place piston and barrel fixture in test bunker. The bottom of the barrel, with the piston protruding, is placed on a steel plate. The input charge rests on top of the barrel.

12. Connect detonation wire to input charge.

13. Detonate charge.

14. If necessary:

    a. Use mill to section piston and barrel fixture at depth where reactive material is placed such that reactive material is exposed.

15. Collect reactive material and send to laboratory for elemental and phase analysis.

EXHIBIT 2

2. Evaluation of Perforators Using Stressed Rock Targets

2.1 Introduction

The purpose of Section 2 of the API RP 19B is to provide a basis for the evaluation of perforators with tests using rock cores at simplified insitu conditions. The primary useful data output from these tests will be the penetration depth produced as a function of target composition and state.

The intent of this section shall be to provide specification for preparing targets, conducting tests, and reporting data so that consistent and comparable results can be obtained. The data produced shall be suitable for first order estimation of downhole performance, given suitable predictive models.

The structure of this section shall be as follows:
a. Target selection – requirements, specifications, and preparation procedures
b. Test equipment – requirements, specifications
c. Standard qualification test – description and procedures.

The RP was updated by a collective group and was based on a large scale round robin test series conducted at numerous facilities. The test series aimed to determine if there were any inconsistencies that could be derived from the process or specific test equipment used during the process, to determine this a single lot of shaped charges and single block of sandstone was used. From the testing it was determined that there were no significant variations attributed to the vessel equipment, UCS equipment, or company specific practices. This RP was shown that *within the standard test conditions it* is statistically capable of reproducing consistent data at multiple facilities.

2.2 Sandstone Target – Requirements & Specifications

2.2.1 All testing shall be conducted using natural stone targets, obtained from blocks of stone, quarried from the earth.

2.2.2 The standard target shall be homogeneous sandstone, such as Berea Sandstone.

2.2.3 The porosity of the target shall be between 18.5% and 21.5%, which is a typical range of porosity for Berea Sandstone.

2.2.4 The Uniaxial Compressive Strength (UCS) of the saturated target shall be a minimum of 5700 psi based on plug and/or scratch test data as determined below in Section 2.3.4.

2.2.5 The target shall be a right-circular cylinder obtained from the natural stone block. The OD of the target shall be between 102 to 178 mm (4 to 7 in.) with an allowable tolerance on the OD of +/- 2.5 mm (0.1 in.). The length of the target may vary depending on the expected perforation depth. The ends of the target shall be flat and parallel to each other.

2.2.6 The bedding plane orientation of the target shall be parallel to the target axis. The testing company shall know the target strength in the direction of charge penetration.

NOTE Strength measurements perpendicular to bedding planes will be greater than parallel to bedding planes for most targets.

2.2.7 All targets shall be vacuum saturated with Odorless Mineral Spirits (OMS) prior to testing, and shall be stored in a container of this fluid until used in an experiment

2.2.8 The rock targets should be free of any visible crack or flaws.

NOTE Cracks visible on a core AFTER testing are common. These cracks may or may not have caused experimental error. Cracks which have visible charge debris inside them most likely were formed during the

perforation event. These cracks may also propagate after removing stress from the target and may or may not contribute to experimental error.

2.3 Sandstone Target – Preparation & Characterization Procedures

2.3.1 Cutting

Diamond core barrels and saws are preferred for cutting of round targets and core plug.

2.3.2 Drying

The cut and sized targets shall be oven dried for at least 24 hours, and to a constant mass (mass change of 1 gram or less in a 24 hour period) in a ventilated oven that is maintained between 93.3°C and 98.9°C (200°F- 210°F). once the target has been dried it shall remain in the oven at temperature until it is ready to be evacuated.

2.3.3 Evacuation, Saturation, and Porosity Determination

2.3.3.1 Just prior to placement in the evacuation chamber, the target should be weighed to the nearest gram on a scale, with suitable accuracy and range, to determine the dry mass of the target. The target mass shall be determined using a scale with a precision of 1 gram for loads of 1000 grams or greater.

NOTE Scales used for this measurement shall be, at a minimum, calibrated annually.

The target shall be evacuated inside of an air-tight chamber provided with a suitably sized evacuation port and vacuum pump to maintain a minimum vacuum of 29 inches of mercury for a minimum of 3 hours before admitting any saturating fluid.

2.3.3.2 The saturation fluid shall be Odorless Mineral Spirits (OMS).

2.3.3.3 The target shall be saturated by slowly admitting the saturating fluid into the bottom of the chamber with the target still under full vacuum. Care shall be taken to allow the fluid to be imbibed or wicked into the target. Under no circumstances should the liquid level be allowed to rise over the saturation line visible on the target OD. The target is completely saturated when the saturation line meets the top surface of the rock and can visually be identified as fully saturated. After full saturation the vacuum should be maintained for a minimum of two additional hours, after which the pressure shall be slowly increased to atmospheric.

2.3.3.4 After saturation is complete, the target shall be removed from the evacuation chamber, immediately wiped free of loose liquids, and weighed again, to the nearest gram, to obtain the saturated mass. The same scale and calibration requirements apply as mentioned above in 2.3.3.1.

2.3.3.5 The pore volume, V_p shall be calculated by dividing the difference in mass in the saturated and dry states by the density of the saturating fluid. The bulk volume V_b shall be calculated from the physical dimensions of each individual target. The porosity of the target shall then be calculated using the following formula:

$\Phi = (V_p / V_b) \times 100\%$

2.3.4 Uniaxial Compressive Strength (UCS) Determination

2.3.4.1 All persons or organizations performing UCS testing shall meet all applicable requirements of ASTM Standard D3740 (current edition); “Practice for Minimum Requirements for Agencies Engaged in Testing and/or inspection of Soil and Rock as Used in Engineering Design and Construction.”

2.3.4.2 The UCS of each target shall be determined by a core plug test per 2.3.4.3 or a scratch index test per 2.3.4.4.

2.3.4.3 The first acceptable test method shall be a core plug test as described in Method C of ASTM Standard D-7012 (current edition), unless specified otherwise below. Please refer to Section 1.2.3 of the latest edition of this standard for complete details on how to correctly perform tests that satisfy the testing criteria.

2.3.4.3.1 All core plug samples shall be prepared following the recommended and required practices listed in ASTM Standard D4543 (current edition); "Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerance", unless specified otherwise below.

2.3.4.3.2 Three core plugs shall be cut from each end of the target in the direction of penetration. If apparent, and possible, all three core plugs should be from the same bedding plane region.

2.3.4.3.3 The rock specimens shall be right circular cylinders of 0.95 inch minimum diameter, with a length to diameter ratio of 2.0:1, and up to a maximum of 2.5:1. Cube samples are not acceptable for this test.

2.3.4.3.4 The ends of the core plug shall be ground or machined flat and parallel to each other.

2.3.4.3.5 All core plugs and the target shall be identically prepared. Special care should be taken to ensure core plugs or target do not dry out during UCS testing.

2.3.4.3.6 Measure the UCS of all 6 core plugs. A core plug measurement shall be considered valid only if the dominant failure surface observed is one of shear (e.g. diagonal to loading direction, at ~45 degrees. – see Figure 2 and Figure 3 for examples of a shear failure.

2.3.4.3.7 Report UCS as the average of all valid end core plug measurements. A minimum of 4 valid core plug measurements is required in order for the target to be considered for perforation testing.

2.3.4.3.8 If required by the test system design, the loaded end of the sample shall be fitted with a spherical seat or bearing surface to minimize any misalignment between the axis of the sample and the direction of the applied load.

2.3.4.3.9 The loading frame or device shall be of sufficient capacity to apply load at a rate conforming to and following the requirements of Section 10.4.1.1 in D7012.

2.3.4.3.10 Load shall be applied continuously and without shock at a stress rate between 0.20 MPa/second and 1.0 MPa/second(30 PSI/second-145 PSI/second).

NOTE This means that the loading rate in LBF/second is a direct function of the sample diameter.

2.3.4.3.11 The stress application rate shall vary by no more than 10% during the test.

2.3.4.3.12 The stress application rate shall be chosen to produce a sample failure in compression in a test time of between two (2) minutes and fifteen (15) minutes.

2.3.4.3.13 The stress rate chosen shall be adhered to for ALL tests for a given series of investigation.

2.3.4.3.14 Axial Load shall be applied until the stress on the sample decreases and/or the sample fails.

NOTE The sample should fail in shear mode to be valid. Failure along a bedding plane or in a direction parallel to the bedding planes shall render a test result invalid (see Fig 2).

2.3.4.4 The second acceptable method of determining the UCS shall be via a Scratch Index Test. This method uses specialized equipment available from different manufacturers, and develops a strength index profile along the OD of the target, in the axial direction.

2.3.4.4.1 This test if used shall be done by trained personnel, following the procedures and specifications provided by the test system manufacturer.

2.3.4.4.2 The test machine is designed to measure a shear force and a normal force on a Polycrystalline Diamond Cutter (PDC) of known width that is cutting a constant depth at a constant speed. The equipment manufacturer's software then calculates the required compressive strength of the rock material that would be necessary to produce the measured forces.

2.3.4.4.3 In order for the cut to be considered valid, the ratio between the shear and normal forces being measured shall be within a specific ratio limit, as specified by each manufacturer. If the ratio is too high, the depth of cut shall be reduced, or a cutter with a narrower width shall be used, or the speed shall be reduced.

2.3.4.4.3.1 Two widths of cutters are available; 10 mm wide and 5 mm wide. Start with the 10 mm wide cutter in all cases, and switch to the 5mm cutter only if you are unable to get a valid cut by reducing the depth of cut and speed of cut as noted in 2.3.4.4.3.

2.3.4.4.4 The saturated but unperforated target will be removed from the fluid tank and will be placed into the scratch test machine target holder and will be securely held in place, such that the target cannot be moved in any orthogonal direction.

2.3.4.4.5 Position the target in the apparatus such that the scratch will NOT be directly on top of a bedding plane (assuming bedding planes are visible). Scratching directly on top of the bedding plane line will produce results that may be higher OR lower than the actual UCS due to the mineralogy of the bedding plane. See Figure 4 for examples.

NOTE Scratching across a bedding plane may decrease the accuracy of the measurement.

2.3.4.4.6 Preliminary cleanup cuts are carried out to ensure that the cutter is making a complete cut (scratch) along the entire length of the target.

2.3.4.4.7 To ensure that clean up cuts are sufficient, one shall examine the raw data and verify that there is no drop off in the measured loads during the scratch. Typically, on smooth surface targets, about three clean up cuts are required to ensure a good scratch value is obtained.

2.3.4.4.8 Once the preliminary cuts are completed, a series of at least two individual scratches are required, following the manufacturer machine instructions, for rocks with non-visible bedding planes. For rock with visible bedding planes, a minimum of three scratches are suggested. The number of scratches above two or three is at the discretion of the testing company.

2.3.4.4.9 Reposition the target in the apparatus by rotating the target by between 90 and 120 degrees, and then repeat the scratch process as per 2.3.4.4.4 through 2.3.4.4.8.

2.3.4.4.10 When all scratching is completed on a target, the scratch(es) on the target OD (~3 mm deep) shall be filled with hydrostone or 5 minute epoxy, if required, and the target will be returned to the fluid tank until needed for a test.

2.3.4.4.11 The scratch data shall be analyzed using the test machine's Analysis program, and then averaged and plotted, which will produce a value of the UCS Index of the target continuously along the entire length.

2.3.4.4.12 For each cut recorded, the first half inch and the last half inch of the reduced data shall be discarded. All remaining data for each cut shall be averaged and plotted as UCS Index vs. Position. Be sure to match the position data for each scratch, so that the average UCS Index obtained are comparable.

2.3.4.4.13 Also calculate the AVERAGE UCS Index for each scratch cut (discarding the first half inch and last half inch) and record this value into the results data table for that particular target.

2.3.4.4.14 The data table will then calculate an overall AVERAGE UCS value for the test target. The average of both scratch UCS values (0deg and 90-120deg) will be used to determine the average UCS for the target.

2.3.5 Storage

The target shall be stored (fully submerged) in the same type of fluid with which it was saturated; following characterization until assembly into the confinement vessel.

2.4 Test Setup

2.4.1 Target and Casing Plate Assembly

The target shall be provided with a faceplate on the end to be perforated that simulates the well casing and cement sheath between the casing and the borehole wall. There shall be a flexible jacket that transmits simulated overburden stress to the sample. There shall be a faceplate on the end that is not to be perforated to prevent confining pressure from entering the target.

- The faceplate on the perforated end of the target shall consist of 0.50-inch (±.020-inch) thick wall simulating the well casing, and shall be made of AISI 4140 steel (UNS G41400 or equivalent) as defined in and conforming to the current version of ASTM A29. The face plate material shall be in the heat treated (quenched and tempered) condition, and shall have a hardness of 18-22 Rockwell C, minimum 80ksi yield strength. The plate shall be at least 1.5-inches in diameter or at least 1.5-inches square.
- The cement sheath between the simulated casing and target shall be 0.75-inch (±.030-inch) thick, at least 1.5 inches in diameter, and will consist of standard API Class A, ASTM Type I, or ASTM Type II cement. The cement shall cure for a minimum of 5 days.
- The flexible jacket surrounding the target shall be of any flexible material, such as Buna-N (nitrile), urethane, or other elastomers that are compatible with both the working fluid and the saturation fluid. In order to ensure that the overburden stress is properly transmitted to the target, the jacket shall not be thicker than 0.75 inches. Refer to Figure 1.

NOTE Care should be taken to ensure that the flexible jacket is securely fastened to the faceplates; this will prevent leakage of the confining pressure into the target which will affect results. Leakage of the working fluid into the target will invalidate the test. If the working fluid is different from the target saturation fluid, the target will be deemed contaminated, and may not be used in later official tests.

2.4.2 Wellbore Fluid Clearance

A fluid clearance shall be established between the outer face of the perforated faceplate and the OD of the simulated scallop. This clearance shall be 0.75 inches and be filled with water or OMS. Grease or adhesive caulking maybe used to prevent the liquid from leaking from the clearance gap.

2.4.3 Gun Body

An actual or simulated scallop or gun body shall be placed over the clearance gap. If a simulated scallop or gun body is used it shall be of the same thickness as the actual carrier that is used for the shaped charge that is being tested, and may be mild steel. A stand-off ring may be used to create the internal gun configuration, but shall accurately represent the actual stand-off between the face of the charge and the ID of the gun body.

2.4.4 Shaped Charge

The required number of charges shall be samples taken uniformly from a minimum production run of 300 charges and packaged in the manufacturing/service company's standard shipping containers. These charges shall be stored for a minimum of four weeks prior to testing to allow some aging to occur. Charges shall be selected from one or more unopened containers.

2.4.5 Detonating Cord

The detonating cord shall be used to initiate the test charge and shall meet the same temperature rating as the charge being tested. It shall be of the same grain weight, detonation velocity type (XHV or regular), and size/configuration as will be recommended for use in the system being tested. The detonating cord shall be used in the same orientation and manner that it would be in the actual system in which the charge being tested is employed.

2.5 Confinement Vessel

2.5.1 General Design Guidelines

The design and operation of the pressure confinement vessel shall be left to the discretion of the individual testing company. Figure 1 is meant as to show the concept to assist in the basic description of conducting a test. The target should be constrained in the longitudinal direction to prevent tensile failure. However, at a minimum, the inside diameter of the pressure vessel shall be at least 1-inch larger than the outside diameter of the confinement sleeve. The test assembly shall be concentric within the test vessel, giving a minimum 0.5 inch annular fluid gap. The vessel shall also be of sufficient length to accommodate target lengths as described below in section 2.7.

2.5.2 Pressure Capability Requirements

The confinement vessel, for the purposes of this test, shall be capable of safely handling pressures up to 9500psi (15000 psi recommended).

2.5.3 Wellbore System

A wellbore chamber is not required; however, a wellbore chamber may be used as long as no more than 100psi pressure exists in the chamber during the test.

2.5.4 Pore System Ventilation

Elevated pore pressure is not permitted and could have an impact on the performance of the perforator. Therefore it will be necessary to ensure a suitable mechanism exists to bleed pore pressure which can otherwise build up during application of confining stress (Skempton effect). Pore pressure venting shall be through either a small hole through the casing plate, a hole/vent tube connected to the unperforated end of the target, or both. The minimum vent hole / port diameter shall be 0.075-in. Vent hole(s) shall be in direct contact with the target surface(s), and care shall be taken that this venting mechanism does not become obstructed with debris, sand grains, grease, etc. In conjunction with this venting mechanism, the target shall be held at elevated confining stress (prior to perforating) for a sufficient time to ensure that any induced pore pressure has fully diffused from the entire pore space. The required time is a function of the vent hole location, whether 1 or both ends of the target are vented, target length, and permeability. Higher permeability, shorter targets, and venting both ends all will decrease this required time.

2.6 Test Conditions

2.6.1 Pressure Conditions and Number of Shots

The pressurizing test fluid used shall be at the discretion of the individual testing company. All tests will be conducted at ambient temperature conditions. Test will be conducted at 3 different confinenment pressure values; 1500, 5500, and 9500 psi (each +/-50 psi). Four valid shots are required at each pressure, and all valid shots shall be recorded.

NOTE Criteria for a shot to be considered valid are described below in Section 2.7.

2.6.2 Testing Procedure

2.6.2.1 Upon installation of the target into the confinement vessel and proper placement of the shaped charge assembly, the confining pressure shall be increased to the desired test pressure. Pressure shall be remotely monitored using calibrated gauges; gauge accuracy shall be ±0.5%.

NOTE Gauges used for this measurement shall be, at a minimum, calibrated annually.

2.6.2.2 After reaching the desired test pressure; the shaped charge shall be remotely detonated. Upon successful detonation, the confining pressure shall be bled to zero. Upon verification of zero pressure the target shall be removed from the confinement vessel.

2.6.2.3 Carefully remove the faceplates from the target and slide the target out of the flexible jacket. Care should be taken since the target may have fractured during the test.

2.7 Data Recording and Validity

For each sample tested, the following data shall be recorded:

Target Properties
- Formation Type
- Diameter, Length, Bedding Plane Orientation
- Porosity
- UCS

Perforator Properties
- Perforator Part Number
- Perforator Explosive Type and Weight
- Simulated Gun System Properties

Test Conditions During the Shot
- Overburden Pressure
- Wellbore Pressure
- Pore Pressure

Perforation Performance
- Casing Through Hole Diameter shall be measured along the short and long elliptical axes with a caliper whose arms readily pass through the perforation and reported along with the average of the two measurements. Hole diameter shall be reported to the nearest 0.01-inch.
- Total Core Penetration – length from target face to the end of the perforation tunnel. The end of the perforation tunnel shall be established as the point where the rock material strength damage ends as qualitatively indicated by manual scraping / probing with moderate force, of the exposed material surface, and shall be reported to the nearest 0.1-inch. This shall be determined visually from a split core, from CT or other non-invasive scanning methods
- Total Target Penetration – length as calculated from the wellbore inside diameter side of the simulated casing plate to the end of the perforation tunnel as defined above and shall be reported to the nearest 0.1-inch.

Data acceptance
Results shall be considered valid only if the following conditions are met (in addition to having followed the above-mentioned procedures):

- Target length - at least 3 inches of un-penetrated core shall remain beyond the perforation tip.
- Jet straightness - the jet tip shall not be closer than 0.75 inches to the core outside diameter.

2.8 Contingencies

In the event a target is not perforated as initially intended (eg due to issues with initiation system or other components of the test system), it will be necessary to troubleshoot according to local procedures. This may involve de-stressing the target. In the event a target is de-stressed, it is required that the suitability of the target be confirmed before resuming testing. At a minimum, before any target is re-stressed for any test in accordance with this section, it shall be inspected for:

- dimensional consistency (maximum of 25 grams lost vs. initial dimensions, prior to first stress cycle)
- mass consistency (no changes vs. initial mass; eg to ensure unaltered saturation, etc.)

- appearance (assess any changes which might indicate infiltration of confining fluid, or induced chips, cracks, etc.)

If any change – quantitative or qualitative – is noted, then the target shall be deemed unsuitable for any testing under this section.

2.9 Special API RP 19B Section 2 Tests

Well environments may require that special tests be conducted to better simulate downhole conditions. The downhole environment certainly varies from one well / formation to another. Any given downhole environment may involve various combinations of rock, fluid, stress, pressure, temperature, casing, cement, and wellbore which differs from the specifications described above for a standard Section 2 test. Therefore this subsection provides a means to shoot and publish witnessed test(s) in a Special API RP 19B Section 2 setup. A Special Section 2 program would exhibit one or more of the following deviations from the standard Section 2 setup, as dictated by specific requirements:

1. Special rock may be used (outcrop rock or reservoir wellcore, as specified)
2. Different saturation fluid and saturation process
3. Different confining stress level(s)
4. Elevated reservoir pore pressure
5. Different wellbore fluid, and/or elevated wellbore pressure
6. Elevated system temperature
7. Different wellbore clearance, wellbore fluid type, casing plate thickness, cement thicknesses, and/or materials – eg to simulate specific casing/borehole configurations
8. Different quantity of test shots (for example if due to limited availability of reservoir wellcore samples)

Except as rendered non-applicable by these deviations, all requirements of sections 2.2-2.8 remain in effect, when conducting a Special Section 2 test program.

Any published data sheets for tests conducted under this subsection shall be clearly labeled “special test”; and the specific deviation(s) noted.

2.10 Data Publication

With the publication of the 3rd edition it is expected that the Section 2 witnessed test data will be also be published and made available on line via the API Registerd Designs process. This Section 2 is issued in conjuction with the following guidance documents which shall be consulted to facilitate witnessing & testing :-

1. API 19B Section 2 Certification Data Sheet (UCS determined by Scratch Test)
2. API 19B Section 2 Certification Data Sheet (UCS determined by Plug Sampling)
3. API 19B Section 2 Witness Instructions
4. API 19B Section 2 Witness report

Only the appropriate Certification Data Sheet will be published via the Registered Designs Process.

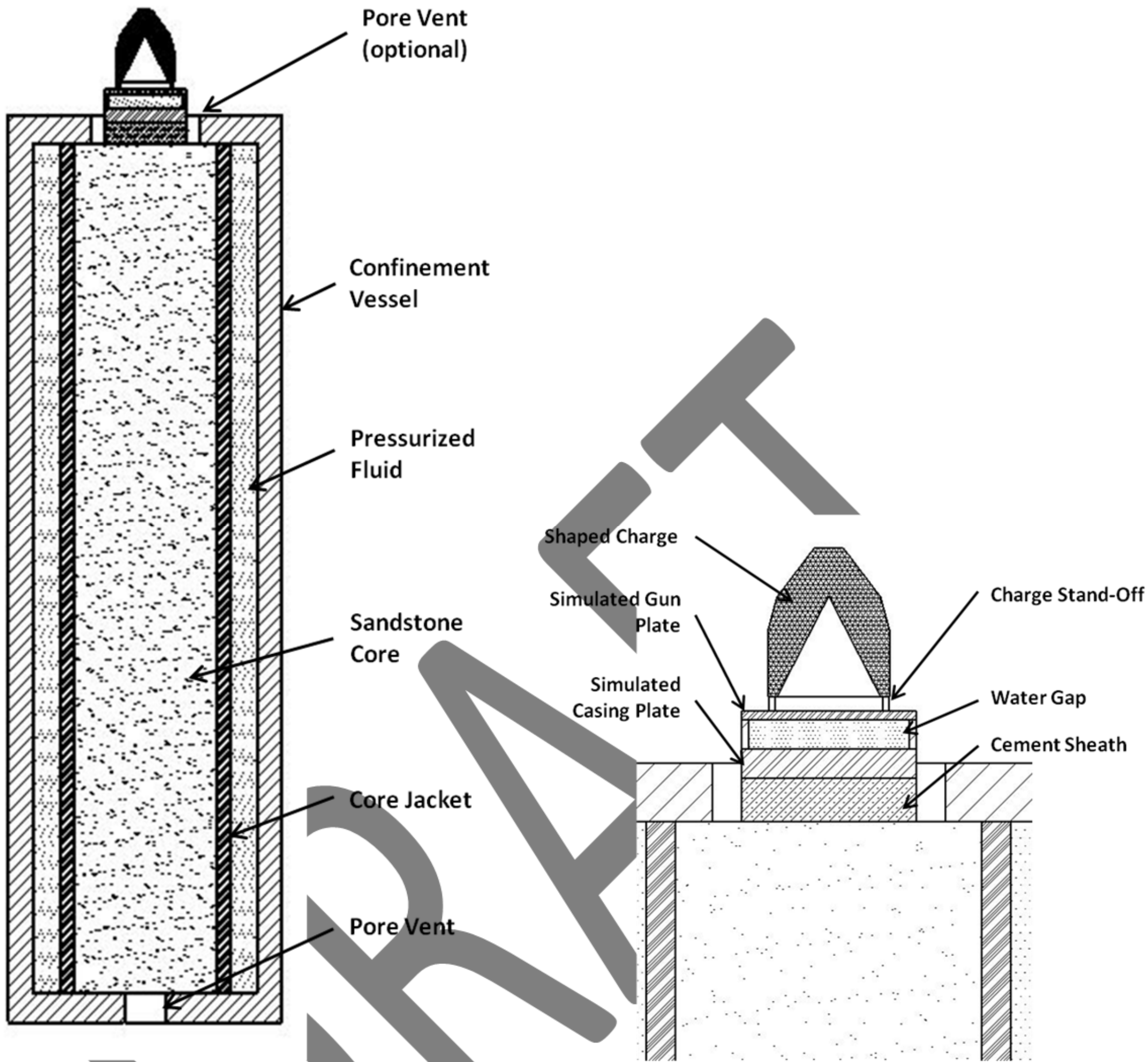

Figure 1: Test Set Up Schematic

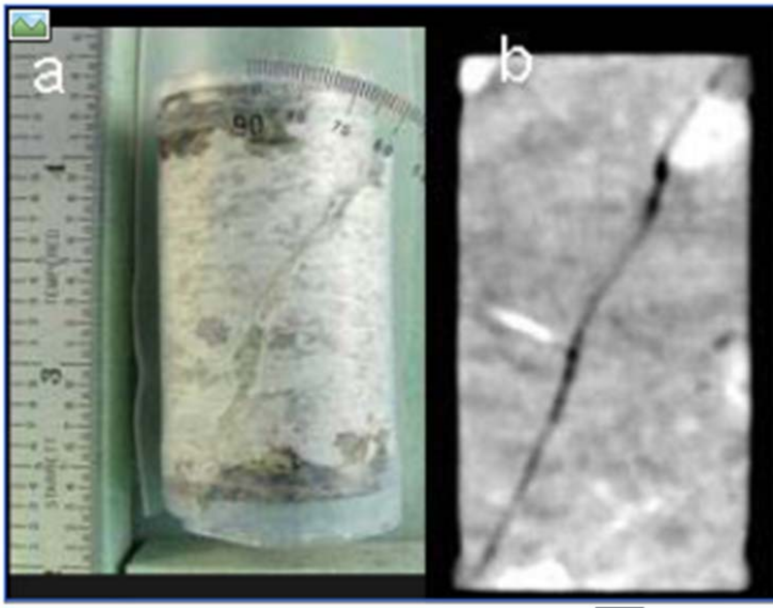

Figure 2: 1 x 2 Test Sample Post Failure; demonstrating 45deg shear failure angle required for a valid UCS test.

Figure 3: 1 x 2 Test Sample Post Failure; demonstrating 45deg shear failure angle required for a valid UCS test.

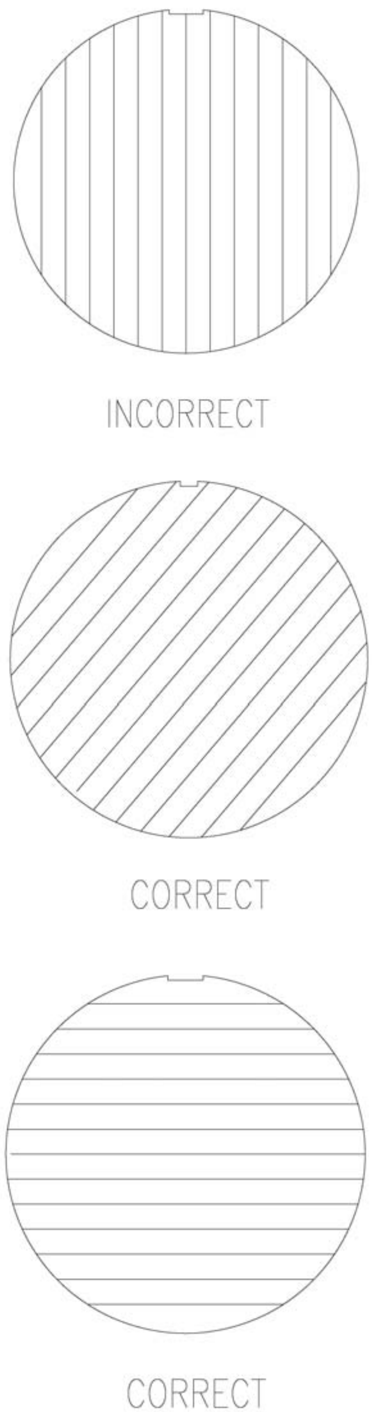

Figure 4: Suggested Position of Cutter Scratch versus bedding planes.

API RP19B - SECTION II CERTIFICATION DATASHEET

Testing Company ______ Date(s) of Testing ______ - ______
Charge Name ______
Manufacturer Part Number ______ Charge Date Shift ______
Explosive Type / Gram Wt. ______ / ______ Charge Case Material ______
Simulated Gun System ______
Comments ______

Target Configuration: ☐ Standard Conditions ☐ Special Test Conditions

	Standard Conditions		Special Test Conditions	
Casing	0.5 inch	4140 Mill HT 18-22 Rockwell	inch	
Cement	0.75 inch	Class A, Type I or II Portland	inch	
Fluid Clearance	0.75 inch	Liquid (OMS or Water)	inch	
Overburden Pressures	1500 / 5500 / 9500	psi		psi

Target Properties:
Target Type ______
Saturating Fluid ______ Bedding Plane Orientation ______
UCS Measurement Method Scratch Test

Measurements	Confinement Pressures														
	psi					psi					psi				
	1	2	3	4	avg	1	2	3	4	avg	1	2	3	4	avg
Casing Through Hole, minor, in.															
Casing Through Hole, major, in.															
Casing Through Hole Average, in.															
Total Core Penetration, in.															
Total Target Penetration, in.															
Target UCS, psi															
Target Porosity, %															

Manufacturer's Certification ______ Self ______ Third Party

I certify that these tests were made according to the procedures as outlined in API RP 19B: Recommended Practices for Evaluation of Well Perforators, Third Edition, Month, Year. All of the shaped charges and detonating cord used in these tests are standard equipment with our company and were not changed in any manner for the test. Furthermore, the shaped charges and detonating cord are substantially the same as would be furnished to perforate a well for any operator. The results of this test are intended to be used to predict downhole penetration and hole size. The penetrations reported do not represent the actual performance that may be produced in any given well application. API neither endorses these test results nor recommends the use of the perforator system described.

Certified by ______

Company Official Signature | Title | Date | Company | Address

Name of test as it should appear on website: ______
Name of test as it appears on application and application date: ______

API RP19B - SECTION II CERTIFICATION DATASHEET

Testing Company ____________________ Date(s) of Testing ________ - ________

Charge Name ____________________

Manufacturer Part Number ____________________ Charge Date Shift ________

Explosive Type / Gram Wt. ________ / ________ Charge Case Material ________

Simulated Gun System ____________________

Comments ____________________

Target Configuration: ☐ Standard Conditions ☐ Special Test Conditions

	Standard Conditions		Special Test Conditions	
Casing	0.5 inch	4140 Mill HT 18-22 Rockwell	inch	
Cement	0.75 inch	Class A, Type I or II Portland	inch	
Fluid Clearance	0.75 inch	Liquid (OMS or Water)	inch	
Overburden Pressures	1500 / 5500 / 9500	psi		psi

Target Properties:

Target Type ____________________

Saturating Fluid ____________________ Bedding Plane Orientation ____________________

UCS Measurement Method Plug Sampling

Measurements	Confinement Pressures														
	psi					psi					psi				
	1	2	3	4	avg	1	2	3	4	avg	1	2	3	4	avg
Casing Through Hole, minor, in.															
Casing Through Hole, major, in.															
Casing Through Hole Average. in.															
Total Core Penetration, in.															
Total Target Penetration, in.															
Target UCS, psi															
Target Porosity, %															

Manufacturer's Certification ____________ Self ____________ Third Party

I certify that these tests were made according to the procedures as outlined in API RP 19B: Recommended Practices for Evaluation of Well Perforators, Third Edition, **Month, Year**. All of the shaped charges and detonating cord used in these tests are standard equipment with our company and were not changed in any manner for the test. Furthermore, the shaped charges and detonating cord are substantially the same as would be furnished to perforate a well for any operator. The results of this test are intended to be used to predict downhole penetration and hole size. The penetrations reported do not represent the actual performance that may be produced in any given well application. API neither endorses these test results nor recommends the use of the perforator system described.

Certified by ____________________

Company Official Signature | Title | Date | Company | Address

Name of test as it should appear on website: ____________________

Name of test as it appears on application and application date: ____________________

EXHIBIT 3

4 Evaluation of Perforation Flow Performance Under Simulated Downhole Condition

4.1. INTRODUCTION

The purpose of Section 4 is to provide a basis for the comparison, development, and evaluation of perforators and perforating performance in general through the use of tests looking at the flow performance of perforations shot into rock cores, shot under insitu conditions. The intent of this section shall be to ensure that all entities performing such tests do so in a way that translates improved lab performance into increased performance in the field. This section should NOT be used as a restriction on how a facility is set up and operated. This is best left to the groups performing such tests, and allows for designs to be based on experience, best practices, and improvements in technology. The outline for a "standard test" that should be performed by all entities and parties that choose to perform such tests is also included.

The structure of this section shall be as follows:

a. A basic target preparation and constructions technique specification
b. A basic equipment and technique specification highlighting common test artifacts for consideration.
c. Standard qualification test description(s), including core saturation procedures.
d. Minimum requirements for comparative tests.

4.2. TARGET PERPARATION AND CONSIDERATIONS

4.2.1. Tests shall be conducted using cylindrical natural rock targets, obtained from stone quarries, field outcrops, or from well core obtained from an oil or gas well.

4.2.2. Targets may be cut either perpendicular or parallel to the natural bedding planes in the stone. The choice of bedding plane orientation has implications for test boundary conditions and for data reduction.

4.2.3. The size of the test core shall be at the discretion of the testing company. In general, for charges with 15 grams of high explosive or less, a 4 inch diameter core may be used. For charges with explosive loads greater than 15 grams, a 7 inch target should be used. This is not a strict limit. In many cases useful information can still be obtained for larger charges in smaller cores. The appropriate target size is dependent upon: the charge to be used, the rock strength, rock confinement pressure, and fluid system stiffness.

4.2.4. If necessary, a composite target may be constructed from small diameter field core and some outer shell material in order to create a larger effective diameter. The methodology for doing this shall be at the discretion of the testing company, however in general these methods will increase experimental uncertainty, and may create an indeterminate boundary condition.

4.2.5. Targets can range from 4 inch to 20 inch diameter. Current sizes in use are: 4", 5", 6", 7", 9" 11.5", and 15.5". In general, a lab facility can accommodate most testing requirements with three core sizes, ranging from 4 inch diameter to 9 inch diameter. Increased core diameter can reduce experimental variation.

4.2.6. Core length should be sufficient such that end effects do not influence penetration depth or flow measurements. One core diameter is the minimum required distance between the tip of the perforation and the end of the core, and more may be required. Extra core length can reduce experimental variation.

4.2.7. Target dimensions are to be +/- 0.1" for both OD and length. The ends of the core are to be flat and parallel to each other to avoid error.

4.2.8. The rock targets should be initially free of any visible crack or flaws. A crack to the OD boundary may cause experimental error. Also note that cracks visible on a core AFTER testing are common. These cracks may or may not have caused experimental error. Cracks which have visible charge debris inside them most likely were formed during the perforation event. These cracks may also propagate after removing stress from the core and may or may not contribute to experimental error.

4.2.9. In a given comparative study, target diameter and length should be held constant to not add additional error into the result.

4.2.10. Diamond core barrels and saws are preferred for cutting of round cores to reduce fines that may affect core permeability measurements. This effect is increased for radial flow test configurations. Loose material should be brushed off or otherwise removed.

4.2.11. The cut and sized cores shall be oven dried for at least 24 hours, and to a constant weight (mass change of 1 gram or less in a 24 hour period) in a ventilated oven that is maintained at 200° F, but not higher than 210°F.

4.3. TARGET EVACUATION AND SATURATION

4.3.1. Target saturation can be single phase (water, oil or gas) or multi-phase (water-oil, water-gas, oil-gas, or water-oil-gas). Single-phase saturation may simplify tests, and in some cases may more closely simulate the near wellbore region due to drilling and completion operations. Multi-phase saturation may more closely simulate the virgin or flowing reservoir, or those situations where there are no issues from drilling and completions. Saturation state can affect the geometry of the perforation tunnel. The typical fluids used for single-phase core saturation are Odorless Mineral Spirits (OMS), brine water (3% KCl), or an inert gas (nitrogen). For safety reasons, one should NEVER USE an oil that contains an aromatic fraction (live crude oil), or a combustible gas (methane or other hydrocarbon). The typical fluids used for multi-phase saturation are brine water, followed by OMS or gas.

4.3.2. Just prior to placement in the evacuation chamber, the rock core should be weighed on a scale with suitable accuracy and range to determine the dry weight of the core. The core shall be evacuated inside of an air-tight chamber provided with a suitably sized evacuation port and vacuum pump to a level of 1 millimeter of mercury or less for a minimum of 6 hours before admitting any saturating fluid. Lower porosity or lower permeability rocks may require additional evacuation time and/or additional procedures to ensure that the rock core will be adequately saturated.

4.3.3. The core shall be saturated by slowly admitting the saturating fluid into the bottom of the chamber with the core still under vacuum. Care shall be taken to allow the fluid to be imbibed or

"wicked" into the core. Under no circumstances should the liquid level be allowed to rise over the saturation line visible on the core OD. After the core is completely saturated, vacuum should be maintained for a minimum of two additional hours, after which the pressure is slowly increased to atmospheric.

4.3.4. After saturation is complete, the core shall be immediately wiped free of loose liquids and weighed again to obtain the saturated weight. The porosity of the core shall be calculated using the following formula:

$$\Phi = (V_p / V_b) \times 100\% \qquad (4\text{-}1)$$

4.3.5. The pore volume, V_p shall be calculated by dividing the difference in weight in the saturated and dry states by the density of the saturating fluid. The bulk volume V_b shall be calculated from the physical dimensions of each individual core. The core weights shall be determined at room temperature with a scale with a precision of 1 gram for loads of 1000 grams or greater.

4.3.6. If the core is to be saturated with a second phase, the core shall be placed under confining stress in a vessel resembling a Hassler Sleeve Permeameter. The confinement stress level and pore pressure should match the conditions planned for the core when tested. While under stress, a second fluid shall be flowed axially into one end of the core, displacing the first fluid. Flow at a rate that does not exceed the differential pressure level required to cause non Darcy flow or movement of the fines or clay particles in the pore throats, and continue at this rate until the differential pressure for a given rate is constant or steady state. All cores that will be used in a common test program should be flowed at the same conditions to try and produce an irreducible saturate state to the first fluid that is constant between cores. Some consideration should be given to the gravity effects should the second fluid differ in density from the first, and it may be preferable to inject fluid from the vertical top of the core, the bottom of the core, or both.

4.3.7. After saturating, cores shall be stored in the fluid used to saturate it with, or last flowed through it, until ready for characterization.

4.3.8. After core characterization has occurred, the core shall be stored in the fluid last flowed through the core, until it is ready for use in a perforating experiment.

4.4. TARGET CHARACTERIZATION AND PERMEABILITY MEASUREMENT

Natural rock targets are at this time the best available option for this type of simulation. A significant disadvantage to these targets is the variability between sample sets, although consistency within a given sample set can be very good. Poor quality targets can be a source of considerable experimental error.

Target selection and characterization therefore plays a critical role in order to reduce experimental variation. Target characterization includes permeability, porosity, density, and dimensional properties, as well as mechanical properties such as compressive strength, etc. In a given sample set, it is best practice to evaluate a larger sample of targets than required and then cull targets that fall outside of the normal property range for the sample set.

4.4.1. Permeability Measurement

Sample permeability measurement requirements strongly depend on the type of final flow performance evaluation technique and may vary depending upon the rock used and the information desired from the test program.

For test programs where the final flow performance is desired to be CFE (Core Flow Efficiency), samples are recommended to have bedding planes perpendicular to the long axis of the core. In this case, the axial permeability and the diametral permeability in two orthogonal directions shall be measured.

For test programs where the final flow performance is desired to be PR (Productivity Ratio), samples are recommended to be oriented with bedding planes parallel to the long axis of the core. In this case, the axial permeability shall be measured. Convergent flow measurements may also be taken in order to provide information in a strongly heterogeneous rock.

These recommendations will produce conservative results, reduce experimental error, and emphasize the high permeability characteristics of the target.

The methods for performing these measurements are detailed in Section 4.10, but shall be at the discretion of the testing company except for the following:

a. The measurement should be performed under the same effective stress and pore pressure as that used to evaluate the perforated core.
b. In general, the measurement should be performed under the same effective stress as that used during the perforation test.
c. The core should be at the same fluid saturation condition as that used during the perforation test, and the same fluid and range of flow rates should be used in both tests during the flow measurements.
d. Care shall be taken to reduce sources of error as listed in Section 4.6.

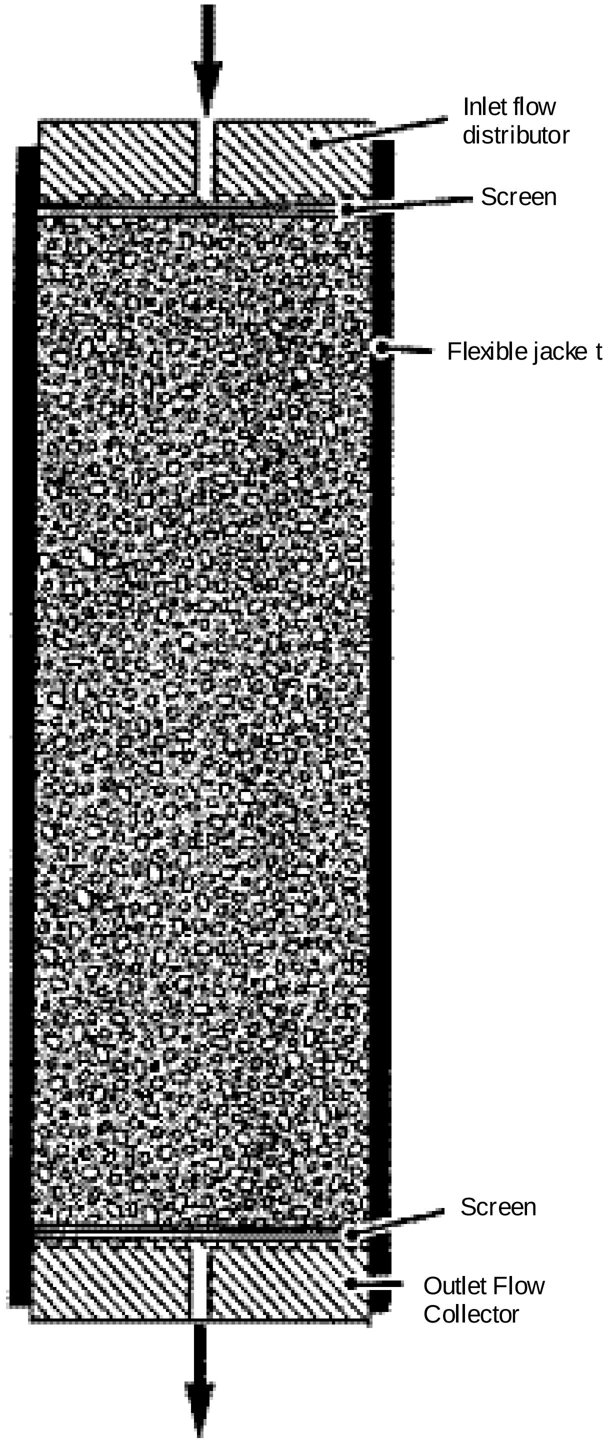

Figure 9: Typical Axial Flow Permeability Equipment

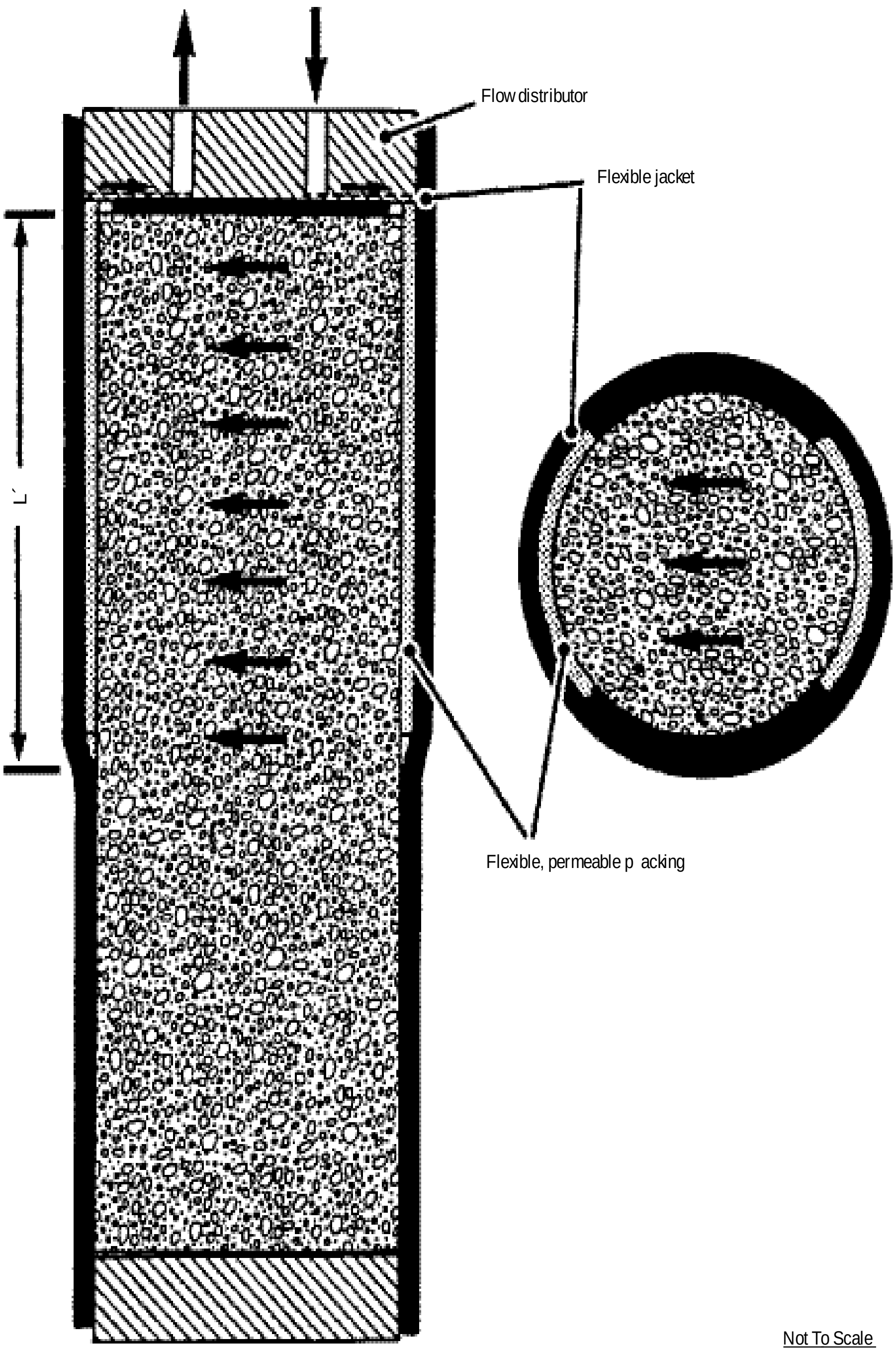

Figure 10: Typical Diametral Permeability Equipment

4.4.2. Mechanical Properties

Mechanical properties may vary from core lot to core lot, and sometimes target to target. Many times there are visual clues to varying mechanical properties. Permeability, porosity, and density may also provide an indication of significant difference. It is nevertheless good practice to measure various properties of each incoming lot, such as unconfined compressive strength, confined compressive strength, grain size distribution, mineralogy, and pore throat diameter. In recent years, scratch index testing has emerged as a means of quantifying unconfined compressive strength of each sample to be tested. Evaluating the mechanical properties of each core can reduce experimental variation.

Alternatively, incoming cores can be tested at standard test conditions against perforators with known performance history in order to qualify targets by batch or lot.

4.5. TESTING EQUIPMENT

4.5.1. General Requirements

The testing equipment required for a Section 4 experiment shall generally consist of the following:
a. Target Confinement System
b. Simulated Wellbore System
c. Surge Simulation System
d. Simulated Perforating Gun System
e. Pressure Control and Measurement System
f. Flow Control and Measurement System
g. Data Acquisition System

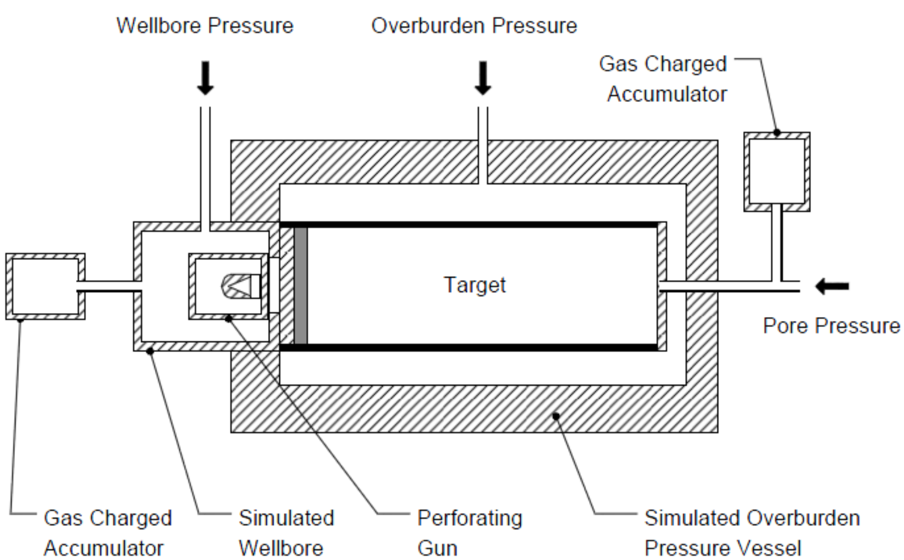

Figure 11 - Schematic of Typical Testing Equipment

4.5.2. Target Confinement System

The target confinement system is composed of the target assembly and a confining pressure vessel that is designed to apply uniform hydrostatic stress to the target. The inside diameter of this vessel shall be of sufficient size to not cause test artifacts. Application of load shall be controlled and be of a rate that will not cause sample problems due to loading. The composition of the jacket shall be an elastomer material, capable of adequate deformation to seal on the core and endcaps as required. Consideration should be given to the temperature and fluids that the jacket will be exposed to. System pressurization fluid is at the discretion of the testing company. Using fluids incompatible with the test process can cause target contamination and invalidate the test results.

4.5.3. Simulated Wellbore System

The Simulated Wellbore System consists of the wellbore pressure vessel that when connected to the target confinement system allows for the creation of three distinct pressure regimes (confining, wellbore, and pore). The design of the vessel needs to consider the dynamic shock events that will occur inside and appropriate factors of safety must be used to account for these conditions. The design also needs to consider the wide range of fluids that this vessel could be exposed to. Proper material selection is critical to ensure safety when designing and using a vessel that will be subject to high stress and pressure, dynamic shock, corrosives and caustics. Improper material selection can be dangerous. The wellbore volume needs to be of sufficient volume to contain the simulated perforator gun, but must be controlled as much as possible to match appropriate perforation conditions. The effect of wellbore volume and configuration is not well defined, but one should expect that changes in volume and geometry will significantly affect the response of the system to dynamic pressure events. Debris or test fixture movement during the perforation event may obstruct the perforation tunnel entrance. Depending on the parameters of the test, this may be significant or a source of experimental error. Other considerations include explosive loading procedures, proper data collection, and flow paths during and after the perforation event.

4.5.4. Surge Simulation System

The Surge Simulation System shall be used to supply the “surge flow” into and/or out of the test target during the perforation event. This surge flow is meant to mimic the response of reservoir and the wellbore to the creation of the perforation and casing entrance hole. This surge flow is most typically done with accumulators. In the baseline case, the goal shall be to provide a constant pressure boundary condition at the reservoir side of the target. To this end there should be minimal restriction to flow in the plumbing between the pore side accumulators and the core. Increasing the volume of accumulators on the reservoir side will also minimize the loss of reservoir pressure after perforating. The level of gas precharge on the reservoir side accumulators will affect the amount of fluid available for the surge flow and the final pressure of the pore fluid after perforating. The amount of accumulation volume and design of this system shall be left to the testing company as part of the overall design of the facility and experiment. This system can be used to tailor the amount of perforation clean up and to compensate for geometry driven dynamic system events.

4.5.5. Simulated Perforating Gun System

The simulated perforating gun system shall consist of a sealed chamber containing the charge, detonating cord (if used), and detonator. It must be designed to mimic the gun that matches the charge being used in the experiment. It must have a realistic thickness and design as a field gun in the area where the charge would penetrate the gun body, including the scallop. It must match the in-gun standoff that the charge would have in a field gun used in a relevant application. It should be positioned in the wellbore in such a way to hold and maintain the water clearance between the gun and the simulated casing endcap to match that of the field gun in the wellbore. The internal volume of the gun module is a variable that can be adjusted to affect the dynamic surges during the perforating event.

Two types of gun designs mimicking carrier guns are most common. One utilizes shooting the charge in the true geometry (out the side of the carrier). The second utilizes a design shooting the charge through a flat plate that mimics the wall thickness of the gun and scallop. Each has advantages and disadvantages. The design is left to the testing company to decide which design is possible in their particular system and which one provides the best flexibility and reliability.

Use of exploding bridge wire (EBW) detonators is recommended for safety reasons. Be sure to follow all recommendations and requirements of the EBW detonator supplier that is used, as requirements do vary from manufacturer to manufacturer.

In consideration of the charge selection for use in testing of this type,

a. Every effort should be made to reduce charge performance variation in this type of testing.
b. Verification of performance and repeatability is recommended prior to initiation of any test program.
c. Charges to be used should be thoroughly inspected and examined prior to use to eliminate any that have deteriorated or appear to be suspect.
d. Where possible, all charges for a given test program should come from the same box of charges and/or same date shift code.
e. Minimum run lots are not specified for these tests as it is not useful or meaningful.
f. Origin and description of charges used should be reported.

4.5.6. Pressure Control and Measurement System

The Pressure Control and Measurement System shall consist of the pumps, transducers, and valves used to supply, maintain, and control the high pressure confining pressure, reservoir pressure, and wellbore pressure needed for these experiments. Adequate pressure relief capacity must be supplied to protect the test vessels from over-pressure conditions due to equipment malfunction or operator error. The design and specification of this system is left up to the testing company. The expected minimum accuracies of the pressure measurement devices are discussed in Section 4.8. Pressure measurement and control is extremely important. Variations in pressure control or errors in the differential pressure measurement will introduce major amounts of error and variation into the test results.

4.5.7. Flow Control and Measurement System

The Flow Control and Measurement System shall consist of the flow pumps, controllers, flow meters, and valves used to supply, maintain, and control the fluids being flowed through the test target in either the production or injection directions. Test fluids can include oil, water, or gas in single phase or in various combinations. The required accuracies for the flow measurement equipment are discussed in Section 4.8. The design and specification is left up to the testing company.

a. Flow measurement and rate control are extremely important. An improperly designed system will introduce major amounts of error and variation into the test results. Note, it is recommended for simplicity (but not required) to control the rate and measure the differential pressure for a liquid flow, and to control the differential pressure and measure the rate for a gas flow.

b. Fluid filtration is critical. Improper or inadequate filtration will result in core plugging, which will add error to the pressure drop measurements, which will affect the final results. This should be evaluated for any system as noted in Section 4.8.

4.5.8. The Data Acquisition System shall consist of the required equipment to accurately record all data from a Section 4 test with the accuracy required for each testing type. The equipment configuration shall be at the discretion of the testing company with the exception of the following:

a. Analog to digital conversion can be a source of significant error. The use of higher resolution A-D conversion can help to increase accuracy.
b. The system shall be capable of collecting “fast data” at the time of the perforator detonation. At a minimum these measurements should be collected from the wellbore pressure, however gun peak pressure and pore pressure may also be useful to understand system response. In general rates of 5000 samples per second are the minimum acceptable.
c. Care should be taken to reduce noise from detonator initiation and other electrical interference, and proper placement of the transducer to avoid error due to shock reflections.

4.6. TEST TARGET SETUP

4.6.1. Perforating tests shall be performed using cylindrical cores. The core shall be provided with a faceplate on the end to be perforated that simulates the well casing and cement sheath between the casing and the borehole wall. There shall be a flexible jacket that transmits simulated overburden stress to the sample. There shall be a faceplate on the unperforated end to allow for application of pore pressure to the appropriate boundaries of the sample. For axial flow only, constant pressure shall be applied to the unperforated end of the core only. For radial flow, pore pressure can be applied in two different methods. The first method shall be to apply constant pressure to the cylindrical sides of the core via a gap between the jacket ID and core OD that is filled with a permeable media AND to the unperforated end. The second method shall be to apply constant pressure to just the cylindrical sides of the sample using the same method. For most types of rock either can be used. Typical arrangements are shown in Figures 12 and 13. The specific target geometry to be used shall be at the discretion of the testing company, except for the following:

a. Target diameter should generally not be less than 4 inches.
b. The entrance hole shall be positioned in the center of the faceplate and, after shooting, the tip of the perforation tunnel shall not be further than one-fourth of the target diameter from the centerline axis of the target.
c. After shooting, there shall be a minimum distance equal to one target diameter between the tip of the perforation tunnel and the unperforated end of the target.
d. In general, only samples with bedding planes oriented parallel to the core axis should be used in axial-flow geometry tests. This is particularly important when K_v/K_h is low, in which case experimental variation can be significantly increased, but less important when K_v/K_h approaches 1.
e. Simulated overburden stresses shall be applied uniformly to all portions of the sample. Axial and radial stresses may be different, if desired, and if the test system allow for this.
f. The target geometry and setup used shall be tested to provide assurance that no flow is able to bypass the perforation.

4.6.2. For radial flow geometries, the target is configured with a constant pressure boundary condition on the core OD surfaces, an optional content pressure boundary condition on unperforated end of the core, and a no flow boundary condition on the perforated end of the core. The annular gap between the sample jacket and core OD shall be filled with a stress transmission media with permeability at least 100 times greater than the expected permeability of the test core. Refer to Figure 12 for further details and descriptions. In most cases, a high strength proppant can provide this capability. This will address potential test artifacts concerning flow restrictions, media crushing, and poor stress transmission. The face of the perforated end of the core must be sealed with a gasket to ensure that all flow exiting the core comes by way of the perforation. There are several ways to accomplish this, and are left to the discretion of the testing company to select a method and then do the required testing to assure that there is no leakage. The end cap on the unperforated end of the core should normally be configured to include a flow distributor to distribute flow across the entire face of the core and/or to direct fluid to the porous media surrounding the OD of the core.

4.6.3. For axial flow geometries, the target is configured with a constant pressure boundary condition on the unperforated end of the core and a no flow boundary condition on the core OD and perforated end of the core. This is best accomplished with a flexible jacket on the core OD, a flow distributor on the unperforated end, and a sealing gasket on the perforated end. Refer to Figure 13 for additional description and details.

4.6.4. For all testing configurations it is important to minimize all sources of bypass flow around the perforation tunnel, such as:

a. Flow between the core OD and flexible jacket. Use a thick deformable material for the sleeve.
b. Flow between the cement in the endcap on perforated end and the core. Use a gasket of some sort to stop flow path.
c. Flow between the steel endcap and cement in the endcap. Use a cement or grout mixture that does not shrink or that expands while curing.
d. Any bypass leaks in the flow system. Ensure that all flow has to go into and through the test target and exit through the perforation tunnel.

4.6.5. The flow distributor to be used is best constructed with a series of concentric circular grooves and radial connecting grooves, such that a balance between axial stress transmission and the constant pressure boundary condition is reached.

a. Too small an area in the grooves and rings will cause excessive pressure drop.
b. Too large an area in the grooves and rings will cause an excessively high contact stress between the core and the end plate. This could cause localized failure, releasing fines and affecting the results.
c. Screens may be used between the end of the core and the flow distributor to try and better spread the fluid flow and loading out across the end of the target.
d. The screens are also needed for radial flow geometries to keep the proppant from being washed out back into the inlet flow lines.
e. Materials of construction should consider what pore fluids are envisioned for use.

4.6.6. The endcap used on the perforated end of the core should be flat and flush with both the test fixture and core. Neat oilfield cement or non-shrink grout is recommended. Avoid gaps due to shrinkage, as these will provides sources of error in the results.

4.7. GENERAL PERFORATION TESTING PROCEDURE

The following perforation test procedure is provided to as a basic guideline for testing companies. The actual specific procedures to be followed for a perforation and flow test shall be left to the discretion of the testing company to define and follow. The testing company shall be responsible to technically justify their specific procedures.

4.7.1. Increase confining pressure to appropriate level. Avoid applying stress higher than the planned test condition to the core. Once appropriate confining pressure is reached, increase confining pressure, pore pressure, and wellbore pressure either simultaneously or sequentially until desired testing conditions are reached. A bypass line between pore pressure and wellbore pressure is useful during this operation in order to keep pressures equal until ready for final conditions. Other test conditions, such as specialized wellbore fluid, may prohibit this or require alternative configurations.

4.7.2. Allow sample to equalize. Lower permeability targets may require additional time for induced pore pressure to bleed from the target.

4.7.3. Initiate or arm trigger for high speed data collection systems if present.

4.7.4. Arm and detonate perforator.

4.7.5. Allow well pressure and pore pressure to equalize.

4.7.6. If desired, the equalized wellbore/pore pressures may be slowly reduced to a lower or ambient pressure while keeping effective stress constant. Fluctuations in effective stress or differential pressure between the pore and wellbore may invalidate the test. Backpressure can be effective in reducing test time.

4.7.7. Isolate surge system from flow lines.

4.7.8. Flow shall be initiated through the sample by applying desired draw down or flow rate. This value will depend on the flow geometry chosen and effective permeability of the perforated sample, but should not exceed the clay or fines mobilization threshold rate of the target.

4.7.9. Flow should be continued at initial rate until steady state is reached, ie flow rate and pressure drop are constant, and temperature measurements have equalized.

4.7.10. Flow at same rates or pressure draw down as when the core was characterized. These may be different depending upon the discretion of the testing company. Do not exceed the maximum flow rate of the initial characterization, or the pressure differential by twice original maximum.

4.8. SYSTEMS CALIBRATION AND TEST REQUIREMENTS

At a minimum, all transducers, gauges, controls, and instrumentation shall be calibrated against a suitable reference standard at intervals not exceeding one year, per ISO 9001 standards and procedures (current edition). It is best to calibrate the transducers in place, utilizing all of the cables, amplifiers and DAC in the calibration. Not doing so could introduce error and variation into the tests system and subsequent results.

4.8.1. Systems verification tests should be:

a. Conducted prior to the commissioning of any new test system.
b. Conducted after any major modifications to any existing system
c. Conducted every two years, even if there are no major changes

4.8.2. Verification Tests to be conducted are to be designed by the testing company, but shall include, but not be limited to, the following as a minimum:

a. System flow rate. Be able to measure liquid and/or gas flow rates with an accuracy of +/- 1% of full scale. Liquid flow rates may be between 10 cc/minute and 1000 cc/minute for medium and low permeability targets and at rates from 1001 cc/minute to 10,000 cc/minute for higher permeability targets.

b. System Pressure Drop. For pressure drops between 1 psi and 50 psi, be able to measure within +/- 0.50 psi. For pressure drops between 51 and 250 psi, be able to measure within 1 psi. For pressure drops between 250 and 500 psi, be able to measure within 2 psi. For pressures greater than 501 psi, be able to measure within 0.5% of the measured value.

c. Viscosity / Temperature / Liquid Density. Temperature measurements should be within +/- 2 degree F of the measured value. Liquid density should be accurate within 1% of the measured value. Fluid viscosity must be measured using suitable equipment and be available in tabular form.

4.8.3. Recommended System Calibration Tests shall be conducted by the testing company following their own procedures and shall include the following:

a. Conduct a test to determine the system pressure loss, excluding the rock core. The test should determine the pressure loss between any pressure measurement location and the rock core face (inlet or outlet end). For this test, a test fixture with infinite permeability should replace the rock core. The pressure drop measurements should be done across the entire range of flow rates that are capable for any given laboratory test system.

b. Conduct a test to verify that there is no flow bypassing the perforation tunnel in the test set up. The designs of these tests are left up to the testing company and would include verification of the following:

   1. No flow leakage between the core OD and the flexible jacket in axial flow geometry tests. i.e., all flow must go through the core, not around the core.
   2. No flow leakage between the core exit face and the core OD for radial flow geometry. i.e., all flow must go through the core and not around the core.
   3. No flow leakage across the outlet face of the core and the perforation tunnel and hole through the end cap. i.e., all flow must exit the core through the perforation tunnel.
   4. No flow leakage around the outside of the cement plug in the perforated end cap and the hole through the steel plate. i.e., all flow out of the perforation tunnel must go through the cement hole and simulated casing exit hole.

c. Conduct a test to verify that the fluid filtration system is adequate by performing a flow test through a non-perforated core and measuring the pressure drop to constant flow. Any increases in pressure differential shall indicate that pore throat plugging is occurring.

4.9. DATA RECORDING

For each sample tested, the following raw data shall be recorded as appropriate:

a. A record of the test geometry and flow boundary conditions

b. Target Properties

   1. Type
   2. Diameter, length, orientation
   3. Preparation Conditions
   4. Permeability, porosity, density
   5. UCS
   6. Casing and Cement configuration and materials

c. Test conditions during both flowing and shooting

d. Perforation geometry data should be collected after all flow testing, including:

   1. Casing Entrance Hole Diameter, Minimum Through Diameter, and Cement Exit Hole Diameter in two orthogonal directions.
   2. Probe Penetration – depth that 24” long 1/8” rounded tip probe can be placed vertically into target with no external force.
   3. Clear Tunnel Penetration - length from target face to first competent structures within the perforation. In general this can be determined by a combination of probing with moderate force, gentle washing of loose material, and visual inspection.

4. Total Core Penetration – length from target face to furthest evidence of penetration in the target. This can be determined visually from a split core, or from CT or other non invasive scanning methods.
5. Perforation Diameter Profile – the diameter of the perforation shall be recorded at 0.5 or 1.0 inch intervals along the length of the perforation. This may be done by recording the coordinates of the perforation walls in tabular form, by sketching the perforation on an appropriate grid, or by attaching a photograph or scan of the perforation, again with an appropriate scale grid. The average perforation diameter shall be recorded to the nearest 0.1 inch.
6. Maximum Tunnel Geometry – the maximum potential diameter and length of the open perforation tunnel. This geometry is produced by scrubbing the perforation tunnel with a brass cylindrical wire brush to remove all weakened rock. Scrubbing shall be "calibrated" against undamaged rock so that it does not remove undamaged rock around the perforation. Diameter of resulting tunnel should be measured and recorded at 0.5 or 1.0 inch intervals along the length of the perforation.

e. A tabular record of all collected and calculated flow data, including flow rate, inlet pressure, outlet pressure, differential pressure, inlet and outlet temperatures, viscosity, fluid density, and permeability or other measure of flow performance.

f. A high speed plot of the pressures during the perforation event.

4.10. LIQUID FLOW DATA REDUCTION

Flow data may be presented in either of two formats, Core Flow Efficiency (CFE), or Production Ratio (PR). Convergent Flow Production Ratio (CFPR) may be used as an alternative to Production Ratio in strongly heterogeneous targets. In general, radial flow geometry is better suited to a CFE or a modified CFPR analysis, and axial flow geometry is better suited to analysis with PR and CFPR. Neither CFE, PR, nor CFPR completely describe the flow performance of a given perforation. These calculated values should only be considered in the context of other measurements and the test program parameters. The choice of the data reduction analysis shall depend upon the goals of the testing program, and shall be left to the discretion of the testing company.

Productivity Index, (PI) is defined as the ratio of flow rate, corrected by viscosity of the fluid, to pressure drop and is determined from the slope of a linear curve fit though a corrected flow versus pressure drop data plot, as shown below in Figure 14. PI is only valid within the context of a given set of test conditions and is dependent upon such things as boundary conditions, target properties, and fluid properties.

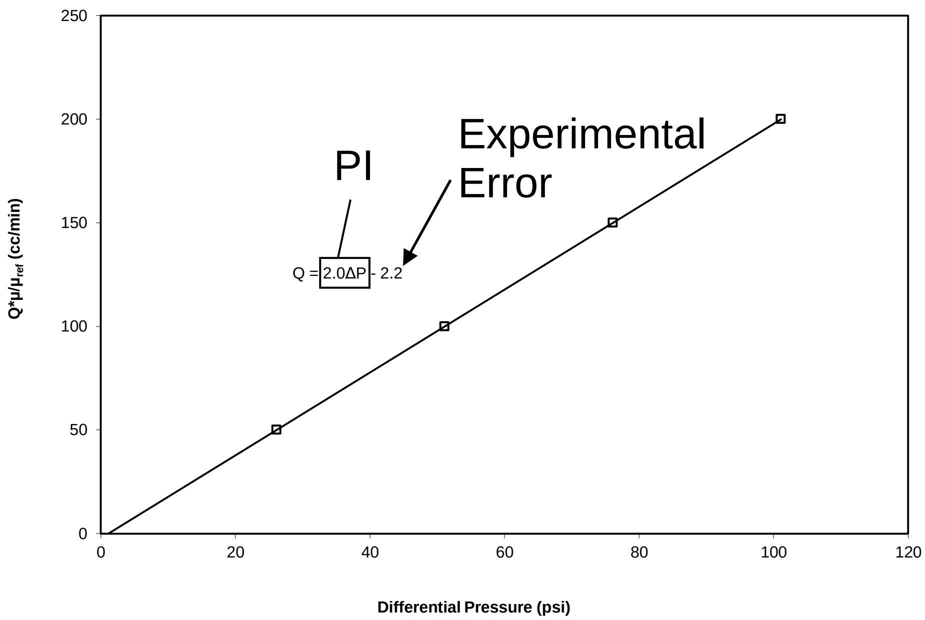

Figure 14: Productivity Index Data Reduction Graph

The corrected flow term Q* is calculated according to Equation 4-2 and has units of cm^3/min:

$$Q^* = Q\frac{\mu}{\mu_{ref}} \quad (4\text{-}2)$$

Where:

Q = measured flow rate, cm^3/min

µ = fluid viscosity, cp

μ_{ref} = fluid viscosity at 75 ^oF and 1 atm., cp

Alternately, Productivity Index may be calculated at a single point according to Equation 4-3:

$$PI = \frac{Q^*}{\Delta P} \quad (4\text{-}3)$$

where

Q^* = corrected flow term, cm^3/min

ΔP = differential pressure corrected for flow system pressure drop, psi.

Productivity Index may be used to calculate perforation performance, and permeability for various boundary conditions.

Axial Flow Permeability, K_a, in mD, shall be calculated according to Equation 4-4:

$$K_a = 30.69\frac{PI\mu_{ref}L}{R^2} \tag{4-4}$$

Where

PI = Productivity Index, cm^3/psi min

μ_{ref} = fluid viscosity at 75 ^oF and 1 atm., cp

L = core length, in.

R = core radius, in.

Diametral Flow Permeability, K_d, in mD, shall be calculated according to Equation 4-5:

$$K_d = 96.43\frac{PI\mu_{ref}}{FL'} \tag{4-5}$$

Where

PI = Productivity Index, cm^3/psi min

μ_{ref} = fluid viscosity at 75 ^oF and 1 atm., cp

L’ = length of 90 degree arc flow inlet and outlet area, in.

F = cross diameter flow correction factor

The Cross Diameter Flow correction factor, F, corrects the apparent diametral permeability for errors due to flow beyond the test region due to axial fluid movement. This correction is especially important for targets with a high ratio of K_a to K_d, but can represent a 10% reduction in apparent permeability for even isotropic targets [5].

This correction is dependent upon the geometry of the cross diameter flow fixture. For 7 inch diameter by 18 inch long cores with 12 inch long 90 degree inlet and outlet flow distributors, F can be calculated according to Equation 4-6:

$$F = 1.232 - 0.2371\ tan\boldsymbol{h}\left[\frac{0.7162\log K_d}{K_a} + 0.612\right] \tag{4-6}$$

For other diametral flow / target configurations, similar correlations for F would need to be developed.

4.10.1. Core Flow Efficiency

Core Flow Efficiency shall be defined as the ratio, Observed Perforation Productivity Index (PI_{perf}) to Open Tunnel Productivity Index (PI_{OT}), according to Equation 4-7:

$$CFE = \frac{PI_{perf}}{PI_{OT}} \tag{4-7}$$

CFE analysis is dependent upon the geometry used to estimate PI_{OT}, as well as the cross diameter flow measurement. Both of these can be sources for experimental variability. CFE analysis is a measure of the flow performance of the entire perforation, emphasizing flow through the side walls of the perforation. In addition, since CFE is generally used in conjunction with radial flow perforation geometry, it is then a measure of the flow performance of perforations produced by radial flow testing, which generally differ from perforations produced by axial flow testing.

The CFE calculation is generally used to estimate the permeability map around the perforation tunnel, most simplistically represented as a constant thickness "damaged zone" of reduced, constant permeability surrounding the entire perforation. This estimate is an input into many perforation and well inflow models. This simplification may be significant, and is an area of active investigation.

Suitable means shall be used to calculate PI_{OT} based on measured Maximum Tunnel Geometry, as specified in Section 4.9, axial permeability, K_a, diametral permeability, K_d, and applied pressure boundary conditions. The best way to calculate PI_{OT} is with a numerical computational flow dynamics (CFD) model. The specific numerical means of calculating the PI open tunnel shall be at the discretion of the testing company.Alternately, for a radial flow target with bedding planes perpendicular to the long axis of the core, the following one dimensional analytical solution may be used:

$$PI_{OT} = 6.516 \times 10^{-2} \frac{1}{\mu_{ref}} \left[\frac{K_1 D}{\ln \frac{R}{r}} + \frac{K_2 r R}{R - r} \right] \tag{4-8}$$

Where:

PI_{OT} = Productivity Index of the Maximum Tunnel Geometry, cm^3/psi min

μ_{ref} = fluid viscosity at 75 ^oF and 1 atm., cp

D = perforation depth, in.

R = core radius, in.

r = maximum tunnel radius, in.

$K_1 = K_d$

$$K_2 = \sqrt[3]{K_a K_d^2}$$

This analytical solution typically overestimates the productivity index compared to the results of CFD simulations.

4.10.2. Production Ratio

Production Ratio shall be defined as the ratio of the Observed Perforation Productivity Index (PI_{perf}) to the pre-shot Productivity Index (PI) of the target, calculated according to Equation 4-9:

$$PR = \frac{PI_{perf}}{PI} \tag{4-9}$$

This analysis may be used for multiple pre-shot and post-shot geometry combinations, including axial flow and radial flow, so long as boundary conditions at the unperforated boundary are the same both before and after the perforation event.

4.10.3. Convergent Flow Production Ratio

Convergent Flow Production Ratio (CFPR) shall be defined as the ratio of the Observed Perforation Productivity Index (PI_{perf}) to the pre-shot Productivity Index (PI) of the target with restricted outlet, calculated according to Equation 4-10:

$$CFPR = \frac{PI_{perf}}{PI} \tag{4-10}$$

This analysis may be used for multiple pre-shot and post-shot geometry combinations, including axial flow and radial flow, so long as boundary conditions at the unperforated boundary are the same both before and after the perforation event.

4.11. GAS FLOW TESTING

Gas flow testing requires additional treatment compared to liquid flow testing. In this section, basic principles, testing procedures and treatment of data are outlined. This is not, and is not meant to be an exhaustive compilation of all possible tests. Tests can be run with dry core/dry gas, cores at irreducible brine saturation (Swi)/humidified gas, or cores at irreducible oil saturation (Sor)/ dry gas. Data may be reduced in terms of either Core Flow Efficiency (CFE) or Production Ratio (PR),

Gas production or injection flow, even at relatively low rates, differs significantly from liquid flow due to compressibility effects and nonlinear friction. As a result, a simple single-parameter Darcy law is not adequate to fully characterize the pressure drop. A convenient method is presented for reducing the experimental data such that the permeability and Forchheimer inertial drag coefficient (c_f) can be determined directly. The choice of the data reduction analysis will depend upon the goals of the testing program, and shall be left to the discretion of the testing company.

Nitrogen, either humidified or dry is recommended for the gas phase. Properties such as viscosity and density may be determined from http://webbook.nist.gov for either isobaric or isothermal conditions. In many cases it is a small error to neglect the pressure drop and temperature change across the core during testing, and use a constant viscosity and density for the data reduction operation.

4.11.1. Target Preparation

Targets should be prepared as recommended in Section 4.2 and Section 4.3. For targets initially brine saturated, humidified gas should be used during the Swi process and testing in order to maintain consistent saturation level. A pressure drop between 10% and 25% higher than desired maximum test pressure drop should be used while desaturating the target. Targets should be weighed at every opportunity to verify saturation state, and stored for only short periods of time if at all prior to perforation.

Humidified gas may be produced by flowing the gas stream through a freshwater chamber located in line immediately adjacent to the target inlet. Increasing evaporation surface area may help to reduce experimental error.

4.11.2. Target Characterization

Targets should be characterized with axial flow and diametral flow in two orthogonal directions. Convergent flow testing should not be used for targets with multiple phase saturation due to potential for local changes in Swi.

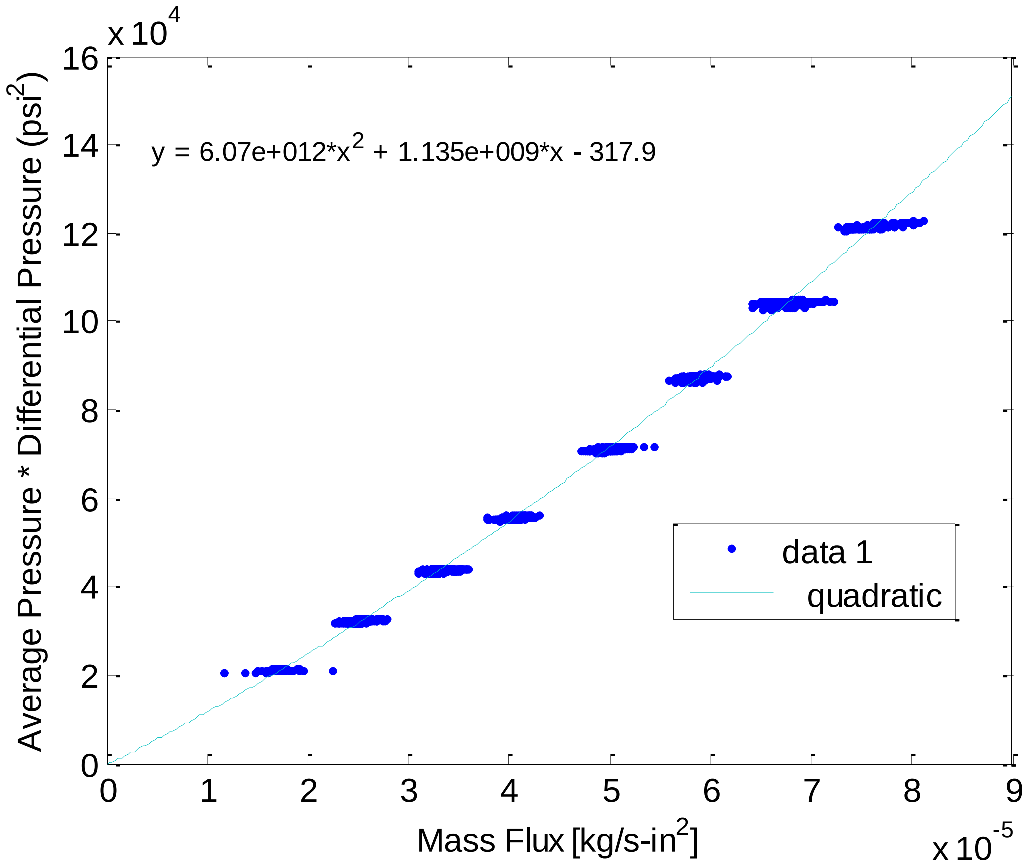

Figure 15 – Axial Gas Flow

The linear and quadratic coefficients, α_1 and α_2 respectively, provide for a direct means of evaluating k and c_f for convergent flow in Equation 4-11:

$$k = 5.79x10^6 \cdot \frac{\mu L}{a_1 \beta}$$
$$c_f = 3.55x10^{-6} \cdot \frac{a_2 \sqrt{k} \beta}{L} \quad (4\text{-}11)$$

Where

K = axial permeability, mD

μ = average fluid viscosity, cP

L = core length, in.

β = ideal gas isothermal compressibility (g/cc/psi)

The case of compressible flow in the diametral direction yields similar results to the axial flow case in Equation 4-12. The flow length is now the quadrant chord length of the core cross-sectional area. The flow area is the product of the chord length and the flowed length. Again, α1 is the linear coefficient and α2 is the quadratic coefficient.

$$k = 5.79x10^6 \cdot \frac{\mu\sqrt{2}Dcore}{2a_1\beta}$$
$$c_f = 3.55x10^{-6} \cdot \frac{2a_2\sqrt{k}\beta}{\sqrt{2}Dcore} \tag{4-12}$$

Where

k = axial permeability, mD

μ = average fluid viscosity, cP

D_{core} = core diameter (in)

β = ideal gas isothermal compressibility (g/cc/psi)

4.11.3. Production Ratio

Gas Flow Axial Production Ratio shall be defined as the ratio of the Observed Perforation Productivity Index (PI_{perf}) to the pre-shot Productivity Index (PI) of the target, calculated according to Equation 4-13:

$$PR = \frac{PI_{perf}}{PI} \tag{4-13}$$

4.11.4. Core Flow Efficiency

Core Flow Efficiency shall be defined as the ratio, Productivity Index (PI_{actual}) to Ideal Productivity Index (PI_{ideal}), according to Equation 4-14:

$$CFE(Q_m) = \frac{PI_{actual}}{PI_{ideal}} = 5.79x10^6 \cdot \frac{\left(\frac{\mu}{2k_h\beta\pi DoP}\ln\left(\frac{R_{core}}{R_{tunnel}}\right) + \frac{c_f}{\sqrt{k_h}}\frac{Q_m}{\beta(2\pi L)^2 L_{eff}}\right)}{\alpha_{1,actual} + \alpha_{2,actual}Q_m} \tag{4-14}$$

where

Q_m=mass flow rate (kg/s)

DoP=depth of penetration (in)

P_L=outlet pressure (psi)

$\overline{P}$ =average of inlet and outlet pressures (psi)

R_{core}=core radius (in)

R_{tunnel}=Perforation tunnel radius (in)

L_{eff}=effective flow length=$\dfrac{R_{core}R_{tunnel}}{R_{core}-R_{tunnel}}$ (in)

Note: evaluation of a_1 and a_2 for radial flow requires fitting a quadratic curve to a plot of the average pressure times the pressure difference vs. the mass flow rate in kg/s, not the mass flux (kg/in^2-s).

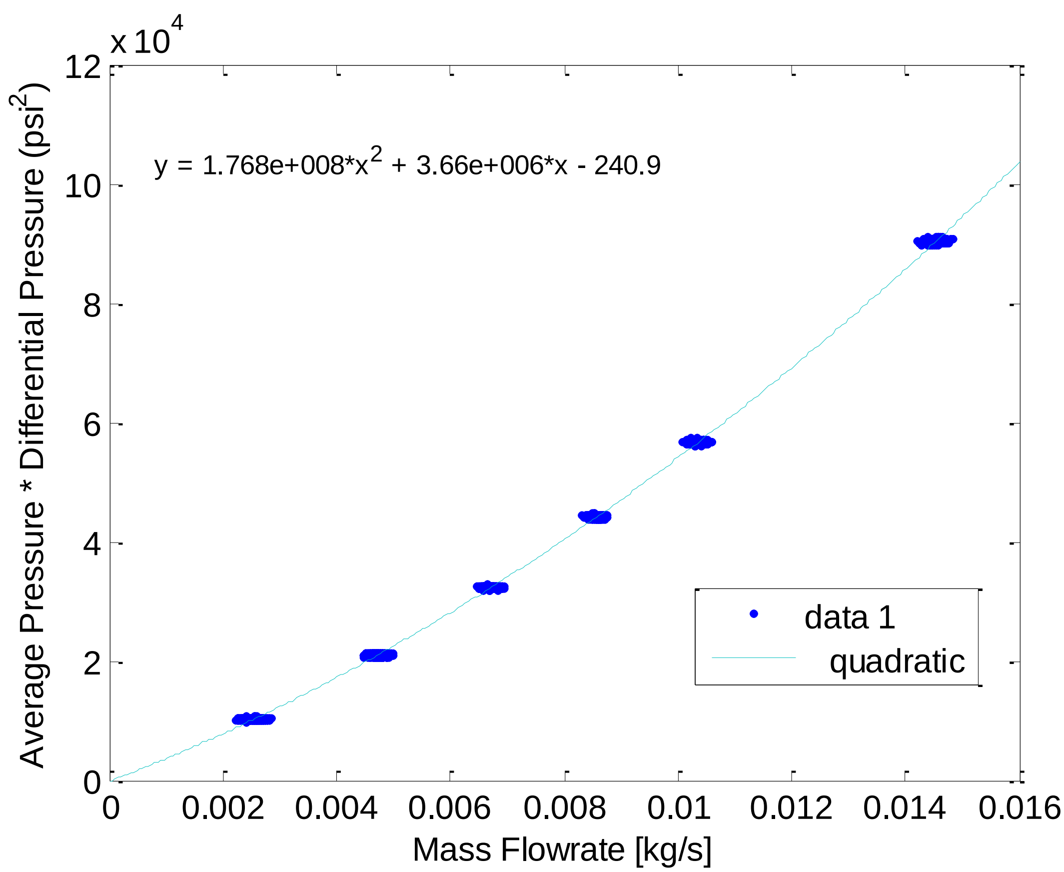

Figure 16 – Post-shot radial flow for a gas saturated core

4.12. STANDARD TEST CONDITIONS

The following additional specifications are provided so that data can be collected and compared under common conditions. All specifications and recommendations above apply. **Data collected under these conditions do not represent, and may not be translatable to, any particular downhole conditions.** Permeability damage caused by the perforator may be different in actual reservoir rock and under actual downhole pressures. Post-shot clean up may differ from standard test results depending on actual reservoir rock properties, the underbalance used, dynamic wellbore storage effects, dynamic pressures surges introduced by the gun system, production drawdown, fluid composition and viscosity, perforating phasing and shot density, and other factors. For best site-specific results, the general test specifications above allow simulation of each of these factors.

The standard test is intended as a means of qualifying laboratory facilities as capable to produce industry consistent results. As the technology of perforation testing evolves, additional critical variables may be identified which are not accounted for in this test. This test is not meant to preclude any laboratory from performing additional measurements or a modified simulation in order to best accomplish the goals of a given internal or customer funded program. Specific recommendations for test configuration for specific programs are left to the discretion of the testing company.

In the best case, core shall be pulled from a bank of standard rock, and charges shall be supplied from a bank of standard charges. Results should be published on a standard data sheet. The compilation of results from all laboratories performing this test should be made public to the API membership.

4.12.1. Rock Samples

Test samples shall be of Berea sandstone or equivalent, meeting the specifications listed in Section 4.2. Ideally, a specific set of blocks will be identified. = For this qualification test, targets shall be cut with bedding planes parallel to the long axis. Target diameter will be as specified by the testing company.

4.12.2. Test Charges

Ideally, two specific, commercially available lots of test charges shall be identified , nominally 15g HMX and 25g HMX. For the qualification test, the testing company may request any size charge for any size target.

4.12.3. Pore Pressure Boundaries

For the qualification test, the core shall be tested in axial flow geometry. Pore pressure shall be applied to the end of the core opposite the perforation only. All previously discussed recommendations regarding target construction shall apply.

4.12.4. Test Fluid

For the qualification test, the test fluid shall be single phase Odorless Mineral Spirits (OMS). The core shall be saturated per single phase saturation recommendations in Section 4.3. The testing company

shall provide a viscosity/temperature/pressure curve which includes the range of temperatures experienced in the test for the fluid used with the test result submission.

4.12.5. Pre-Shot Target Characterization

For the qualification test, the target shall be characterized and data reported per Section 4.4, including and limited to measurement of axial permeability, porosity, density, dimensions, and optionally mechanical properties. Axial permeability shall be measured at flow rates of 60, 90, 120, and 180 cc/min.

4.12.6. Shooting Conditions

The casing plate shall be 0.5" thick 4140 HT Steel, Rc 28-32. Cement shall be 0.75" thick neat Portland cement. A gasket as previously described shall be used between the cement and the core face.

The water clearance between the gun and casing plate (gun clearance plus scallop depth, if present) shall be 0.75 inches. Internal charge standoff shall be as specified by the manufacturer of the charges used in the test. Charge manufacturer shall provide estimate of internal gun volume, but this may be adjusted at the testing company as required.

A pressure – time perforating profile for each charge size is provided. The testing company shall modify appropriate variables as required in order to best match the dynamic events of the provided profile.

Applied static pressures when the gun is fired shall be as follows:

Confining Pressure:	6,500 psi
Pore Pressure:	3,500 psi
Wellbore Pressure:	3,000 psi

This provides an effective rock stress of 3,000 psi and 500 psi underbalance.

4.12.7. Post-Shot Flow Performance Evaluation

The perforated core shall be evaluated in axial flow at, but not limited to flow rates of 60, 90, 120, and 180 cc/min. Measurements shall be conducted in accordance with recommendations in Sections 4.5, 4.6, and 4.7. Data recording shall be conducted in accordance with recommendations in 4.9. Data reduction shall be conducted in accordance with recommendations in 4.10 for axial flow and Production Ratio.

4.12.8. Standard Test Data Sheet

A standard data sheet is provided in Figure 17 for use in reporting the results of the standard test.

SECTION 4 STANDARD TEST DATA RECORDING SHEET

Test: ____________ Date: ____________ Engineer: ____________

ID No: ____________ Technician: ____________

TARGET PROPERTIES

Rock: ____________
Diameter: ____________
Length: ____________
Bedding: ____________
Dry Wt: ____________
Sat Wt: ____________
Sat Fluid: ____________
Porosity: ____________
Density: ____________
UCS: ____________

SHAPED CHARGE

Charge: ____________
Exp. Mass: ____________
DSC: ____________
Gun Syst: ____________
Gun Wall T: ____________
In-Gun Clr: ____________

CASING AND CEMENT

Size & Grade: ____________
Casing Wall: ____________
Cement Type: ____________
Cement t: ____________

CORE PREP CONDITIONS

Confining: ____________
Pore: ____________
Wellbore: ____________
Fluid Flowed: ____________
Temperature: ____________

SHOOTING CONDITIONS

Flow Geometry: ____________
Confining: ____________
Pore: ____________
Pore Fluid: ____________
Effective σ: ____________
Wellbore: ____________
Wellbore Fluid: ____________
Wellbore Temp: ____________

POST-SHOT CONDITIONS

Confining: ____________
Pore: ____________
Pore Fluid: ____________
Effective σ: ____________
Wellbore: ____________
Temp: ____________

PRE-SHOT FLOW DATA

Pre-shot Axial PI: ____________
Pre-Shot Inj. PI: ____________
Diametral 1 PI: ____________
Diametral 2 PI: ____________
Avg. Diametral PI: ____________
Convergent Flow PI: ____________

POST-SHOT FLOW DATA

Post Axial PI: ____________
Post Injection PI: ____________
Post Radial PI: ____________

PERFORATING RESULTS

Gun Entr. Hole: ____________
Casing Entr. Hole: ____________
Casing Exit Hole: ____________
Cement Hole: ____________
Probe Depth: ____________
Clear Tunnel Depth: ____________
Total Pene. Depth: ____________

DATA REDUCTION & ANALYSIS

Axial PR: ____________
Injection PR: ____________
Radial PR: ____________
Convergent Flow PR: ____________

Theoretical PI (CFD): ____________
CFE: ____________
Kc/K: ____________
Single Perf. Skin: ____________

Avg. As-Found Tunnel Dia: ____________
Avg. Scrubbed Tunnel Dia: ____________
Estimated Crushed Zone t: ____________

PERFORATION TUNNEL DIMENSIONS

DEPTH	AS-FOUND	SCRUBBED	NOTES AND COMMENTS
0"			
1"			
2"			
3"			
4"			
5"			
6"			
7"			
8"			
9"			
10"			
11"			
12"			
13"			
14"			
15"			
16"			
17"			
18"			

Engineer Signature: ____________
Date: ____________

Witness Signature: ____________
Date: ____________

Figure 17 – Section IV Standard Test Data Recording Sheet

EXHIBIT 4

<u>DPEX, HaloFrac, CONNEX, and RAZOR Section II Test Procedure</u>

Section II testing will be performed with the following charges:

- EC2-33A2342RC HMX (CONNEX) 30 MAR 2016
- 39g DPEX RDX 3/2014
- 26g DPEX RDX 10/13/16
- 26g DPEX RDX 2/30/17
- 26g DPEX HMX 1/4/17
- 22.7g F.O. HMX 2/1/2018
- EC2-33A2322 HMX (22.7g RAZOR) 02 July 2015

Target Preparation

- Targets are prepared in accordance with API Section II.
- Berea sandstone targets are used. The targets are dried to constant length.
- Berea sandstone targets are vacuum saturated with odorless mineral spirits

Test Fixture

- The test fixture is configured in accordance with API Section II.
- Saturated Berea sandstone target is placed inside the test fixture.
- A cartridge is installed adjacent to the target into the test fixture.
- The text fixture comprises a steel plate and cement case.

Charge Assembly

- The charge to be tested is assembled into a setup fixture in accordance with API Section II.

Detonation

- Test fixture is pressurized to 2000 PSI (4000 PSI for 39g charge).
- Shape charge is detonated.

Analysis

- Pressure is released from test fixture.
- Casing plate, cement plate, and sandstone target are recovered for analysis.
- Sandstone target is sectioned to reveal perforation tunnel.
- Loose material inside the target is washed out.
- Measurements are recorded in accordance with API Section II.